Responses to Anonymous Reviewer #2

The paper documents an interesting and unique emissions dataset of methane for China (excluding Hong Kong and Macao) with timeseries 1980-2010 and gridmaps at 0.5degx0.5deg. This CH_4 inventory is important input in the first place for the 2 National Communications of 10/12/2014 and of 8/11/2012 of China to UNFCCC but also for the Hemispheric Transport of Air pollution Task Force under the CLRTAP and complements there the MIX dataset, documented in Li et al. (2015, ACPD).

The dataset is a bit weak on:

1) the spatial distribution and could benefit of connecting with Tsinghua University (Q. Zhang) and maybe also with PKU-NH3 (X. Huang) to improve the latter.

2) the temporal resolution which would need to be for the HTAP community at least monthly. The seasonality is in particular important for agricultural sectors, which are the major sectors for CH_4. The dataset could improve on this using the temporal profiles in particular for rice cultivation from large literature by Chinese scientists.

The paper compares its inventory with other emissions inventories of USEPA and EDGARv4.2, but should extend this by considering also the national inventories reported by China in its National communications to UNFCCC. The paper also evaluates the changes of the sector-specific emissions over time, but could be completed with a real trend uncertainty and analysis of the major determinants for these trends (such as CH_4 recovery of coal mining as pushed under the CDM, change in conditions of rice cultivation, etc.).

[Response] Thanks for your review and valuable comments. We tried our best to improve our inventory of CH_4 emissions by 1) with higher spatial resolution (0.1 degree by 0.1 degree) and better proxy for the spatial distribution of CH_4 emissions from each sector, and 2) investigating/discussing uncertainty from mitigations such as bio-digesters, coal bed methane (CBM) and coal mine methane (CMM) from registered CDM database, and conditions of rice cultivation, as well as fugitive emissions from oil and gas systems. For the temporal resolution, it is very difficult to estimate the seasonality of CH_4 emissions for all the eight sectors because 1) monthly activity data is hardly available, and 2) monthly mitigation data by digesters, CBM and CMM is not available. Thus we targeted to have annual CH_4 emissions for all the eight sectors in our inventory, although monthly CH_4 emissions from one or two sectors (rice cultivation etc.) could be investigated.

General comments

The documentation of the dataset could be considerably improved by:

1) Giving a full documentation of the sectors covered (maybe making use of the Common reporting format of the UNFCCC reports) and providing also info on what is not included. E.g. what is included in the gas/oil exploitation? Only gas/oil exploration and venting or also the transmission of gas/oil in pipelines, gas distribution networks (very important source, leading to hotspots in cities). What is not included in the coal exploitation? If the emissions of abandoned mines, closed mines are not estimated, this should be mentioned.

[Response] Thanks for the reminder. The fugitive emissions from oil and gas systems include emissions from venting, flaring, exploration, production and upgrading, transport, refining/processing, transmission and storage, as well as distribution networks in this study, which corresponds to IPCC subcategory 1B2. For the fugitive CH_4 from coal mines, the emissions from abandoned mines are not included in our inventory because of the limitation of unavailable data for abandoned coal mines. Except for the emissions from abandoned coal mines, emissions from mining, post-mining, and flaring defined as IPCC subcategory 1B1 are included in our inventory. We added one sentence for the abandoned mines in the revised version.

2) Giving a full documentation of the spatial distribution. References for the geo-spatial proxy datasets are missing.

[Response] We added the references of the proxy data for the spatial distribution (Table S1). In the revised version, we improved the spatial distribution with higher resolution and better proxy data as the reviewers suggested. For livestock sector, we used spatial distribution of number of animals from global livestock production systems (Robinson et al., 2011) as the proxy data. For the sector of oil and gas systems, we used the proxy data from EDGARv4.2 as Schwietzke et al. (2014a). For the other sectors, we used higher resolution of proxy data. We added these details about spatial distribution in the revised version.

3) Elaborating more on the intercomparison of inventories, including the UNFCCC National Communications of China and using the uncertainty recommendations of IPCC GL (2006)

[Response] We already included the comparison between our inventory and the values in 2005 China reported to UNFCCC (Second National Communication on Climate Change of The

People 's Republic of China (SNCCCC); The National Development and Reform Commission: The People's Republic of China national Greenhouse gas inventory for the year 2005 to UNFCCC, 2014. Beijing, China Environmental Press.). In the revised version, we also included the comparison between our inventory and the values with default IPCC (2006) EFs.

The content of the paper could be enriched by:

1) Addressing the seasonality, in particular of the agricultural activities. Ideally providing monthly gridmaps with full documentation of used temporal profiles.

[Response] It is very difficult to estimate the seasonality of CH_4 emissions for all the eight sectors because 1) monthly activity data is hardly available, and 2) monthly mitigation activity data is not available. Thus we targeted to have annual CH_4 emissions for all the eight sectors in our inventory, although monthly CH_4 emissions from one or two sectors (rice cultivation etc.) could be investigated.

2) When describing the emissions at province level, please mention that Macao and Hong Kong are not included. Please compare the emissions magnitude and emission trends between the different provinces. Can there be particular shifts of emissions from one province to another be observed over time? How do the emission factors (per unit of activity) vary amongst the different provinces? Maybe also a mapping of the major emission sectors for each province might be interesting.

[Response] We already limited our inventory in "Mainland China" in our title, and our inventory only included the provinces in Mainland China. We added one table for the emissions magnitude for each province in the SI (Table S3). The emission factors for each province are shown in Table 2. The spatial patterns of each source sector are already shown in Figure 3.

3) Highlighting the fact that the database is a fully consistent bottom-up database with activity data and with recovery (correction factor), which allows to conclude for the trend analysis on the determinant factors of some CH_4 mitigation measures (e.g. CH_4 recovery of coal mining, also CH_4 recovering of the gas/oil exploitation, waste separation, …) with the effect they had on the emissions of China. Please derive which reduction potentials further exist.

[Response] In this study, we would like to give a full documentation of bottom-up inventory for anthropogenic methane emissions in China. Although the future reduction potentials are interesting, we would like to focus on the past three decades in this study and simply mention the possible reduction potentials. Quantitatively estimates of the reduction potentials of CH_4 emissions could be investigated in future study.

4) Discussing an outlook on how to maintain and update the database, at which frequency, using which data sources.

[Response] This database will be regularly updated every two or three years, depending on the availability of activity data.

Specific comments

-) English could be improved: p.1 l13 "have", l14 "contribute"; p4, l18 "are"; p5, l18: remove "emissions", p7, l9 there are few measurements, p12 l26 "and northward of" needs to be corrected; p13, l6, "Yevich", p14, l1 "and 5.2%" should be "to 5.2%"; p.17 l13 "publicly"

[Response] They are corrected.

-) abstract: please mention that it is an ANNUAL bottom-up inventory

[Response] It is added.

-) page 2 line 22: is the 2010 number of EPA reported/calculated or projected. If it is the latter, please make the difference between reported/calculated data and projected data. Also in fig. 2, make the distinction by have e.g. open circle for projected data.

[Response] The EPA 2010 data are projected. Following your suggestion, we used open circle for the 2010 EPA data in Figure 2.

-) page 3: instead of mentioning "English and Chinese literature", please give the real list of references (and mention the language in the reference list).

[Response] We listed the detailed reference list for each sector in the section 2.

-) page 3: formula: what do you mean exactly with "conditions". Do you mean "technologies/ practices, modi operandi"? Moreover: why is the EF not varying in time but only the correction factor?

[Response] The conditions have different meanings for different sectors. For example, condition means underground/surface mines for coal mines, practices/managements (organic input, continuous irrigation) for rice paddy, and burning in households/open field for biomass burning. This word ("conditions") comes from IPCC guidelines vol. 2 (2006). We described the details for EF selections for each sector in the following text. The EF should be varying in time, but little information about time evolution of EF can be available. Thus, we kept the EF unchanged from 1980 to 2010. For the correction factor, normally it correlates with the improvements of technology/practices, or economy development. We can infer the varying correction factor from these indirect indicators. In the revised version, we revised the EF is varying with time in Equation (1), but mentioned that we used constant EFs through the period 1980-2010. "Note that the EFs used in this study did not evolve with time because of limited information about time evolution of EFs." (Page3, line 27)

-) page 4: "CH_4 utilization or flaring"? You mean the "CH_4 recovery instead of venting into the atmosphere"? Please use the standard reporting language (as also in the CDM)

[Response] Yes, it is corrected.

-) page 4 – Table 1: enteric fermentation is (as described in the IPCC GL (2006)) depending for the dairy cattle on the milk production per head and for the non-dairy cattle and other cattle on the live weight per head. These details would be of interest, also complementing the info in the IPCC GL (2006).

[Response] We agree that the enteric fermentation depends on the live weight for the non-dairy cattle and milk production for the dairy cattle. In IPCC (2006), the average milk production for the dairy cattle in Asia is 1650 kg/head/yr, and the live weight of non-dairy cattle in China is 300-400 kg/head (Table 10A.2 in IPCC, 2006), which are from the revised 1996 IPCC Guidelines for GHG inventories (IPCC, 1997). Dong et al. (2004) applied the same live weight for non-dairy cattle as IPCC (2006), but higher milk production for the dairy cattle (4000-5000 kg milk /head/yr) for the enteric fermentation, which has a higher EF of female dairy cattle (Table 1). Yamaji et al. (2003), Verburg & Vandergon (2001) and Khalil et al. (1993) referred or adjusted the EFs from previous studies (Dong et al., 2000; Ward and Johnson, 1990; Crutzen et al., 1986) or IPCC guidelines without giving the information of milk production and live weight for the EFs. In the past three decades, the EFs of enteric fermentation could change with milk production for the dairy cattle and live weight for the non-dairy cattle in China. The constant EFs through the past three decades in this study may underestimate the increasing trend of enteric fermentation, because of the increasing milk production per head of dairy cattle and increasing live weight per head non-dairy cattle during the past three decades in China. On the other hand, the increasing weight of crop production feeding system in livestock and increasing feed of treated straw or residues would reduce the EFs of enteric fermentation (Dong et al., 2004). We discussed the information of milk production and live weight and the uncertainty of possible varying EFs for livestock in the revised version. "Besides the uncertainty of population, the EF of livestock are highly correlated to the live weight per head for meat cattle and milk production per head for dairy cattle (Dong et al., 2004; IPCC, 2006). In this study, as the previous studies, we assumed the EF did not evolve with time because of limited information about the weight distribution of livestock population types besides numbers of animals, although we assessed the uncertainty with different EFs (Table 1). On the one hand, the increasing live weight and milk production per head can increase EFs of enteric fermentation (IPCC, 2006). On the other hand, the increasing weight of crop production feeding system in livestock and increasing feed of treated crop residues can reduce the EFs of enteric fermentation (Dong et al., 2004). The possible changing EF resulting from increased live weight and milk production per head or more feed with treated crop residues should be investigated in a future study." (Page 12, line 5-15)

-) page 5: What do you mean exactly with "biomass burning"? Only small scale or also forest fires, etc. ? Moreover, in formula 2: Why do F and theta not have the index C?

[Response] Biomass and biofuel burning includes firewood and crop residues burning as biofuel in rural households, as well as disposed crop residues burning in open field. The CH_4 emissions from wildfire of natural ecosystems (forests, grasslands etc.) are not included in our inventory, because this inventory only includes the anthropogenic methane emissions. The total CH_4 emissions from wildfire of natural ecosystems in GFED4.1s during 1997 to 2010 is 0.11 Tg CH_4/yr, which is less than 5% of CH_4 emissions from biofuel burnt in households. In formula 2, theoretically, F and θ could be different for different crop residues. However, limited information of F and θ can be available. Thus, we assumed the F and θ are the same across the six types of crops in formula 2.

-) page 6: in e.g. UK we see huge differences in EF for the fugitive emissions from coal mines, because of different geological underground (based on measurements). Is Zeng et al (2006) for China, a much larger country than UK not reporting a similar large variety?

[Response] Zheng et al. summarized regional EFs for six regions (North, Northeast, Northwest, Southwest, Center and South, East of China), which are shown in Table 2. The fugitive EF for coal mines may have large variety across the country because of different coal bed methane store and different coal mining depth in the coal mines, but is not detailed in Zheng et al. (2006). We used the varied regional average EFs from Zheng et al. (2006) to estimate fugitive emissions from coal mines.

-) page 6: Have emissions estimates from abandoned mines, closed mines been omitted?

[Response] On one hand, high moisture in coal strata in China could inundate the abandoned mines, and inhibit the CH_4 emissions from abandoned mines. One the other hand, permeability of coalbed in China is small (~0.001 mD), which indicate the limited CH_4 emissions from abandoned coal mines. Because 1) the emissions from abandoned mines are less than 1% of total emissions from coal mining (NRDC, 2014), and 2) the time series of numbers and locations of the abandoned mines are unavailable (NRDC, 2014), emissions from abandoned mines are not included in our inventory. This is clarified in the revised version (Page 6, line 27-30).

-) page 6 – Table 2: please specify the CH_4 recovery of coal mining gas in the table per province. Please add to the Table also the rice cultivation per province and reflecting as such the difference in cultivated area times the number of cropping seasons. This would be valuable information that adds to the information at Chinese province level in the IPCC GL2006)

[Response] The national CH_4 recovery of coal mining gas in 1994 and 2000 is reported in Zeng et al. (2006). The database of CDM projects only reported 13 registered coal bed/mine methane before 2009. Thus, we assumed that national average value for CH_4 recovery of coal mining gas for each province. For the rice cultivation, the total early, middle and late rice cultivation areas for each province are collected from agriculture statistics yearbooks, and vary year by year. We do not think that it is a good idea to put the yearly varying rice cultivation area of each province in Table 2, otherwise Table 2 is a too "big" to read.

-) page 7 l7: please specify the EFs in kg CH_4 per TJ instead of per kton oil or per m3 gas, because the heat value can change significantly between the different types of oil and different types of gas. Please have an evaluation of the gas distribution leakage. Even though Lelieveld et al (2005, Nature) did not found large leakages from transmission pipelines, it is well-known that the gas distribution networks (especially of the old steel pipeline networks in older cities) are subject to large leakages.

[Response] For the EFs of fugitive emissions from oil and gas systems, based on the EFs in

UFNCCC (2014) and Schwietzke et al. (2014a, 2014b), in the revised version, we adopted the EFs in Schwietzke et al. (2014a, 2014b) for fugitive emissions from oil and gas systems. For fugitive emissions from oil systems, the average EF is 0.077 kt CH_4/PJ (2.9 kg CH_4/m^3 oil), and the low and high boundary of EF are 0.058 kt CH_4/PJ (2.2 kg CH_4/m^3 oil) and 0.190 kt CH_4/PJ (7.2 kg CH_4/m^3 oil), respectively (see Table 1 in Schwietzke et al., 2014a). These values are consistent with the EFs in the table listed by the reviewer#1. The fugitive CH_4 from oil systems increase from 0.36 [0.27-0.98] Tg CH_4/yr in 1980 to 0.68 [0.52-1.86] Tg CH_4/yr in 2010.

For fugitive emissions from gas systems, we used the fugitive emissions rates (FER) to estimate the fugitive CH_4 from gas systems (Schwietzke et al., 2014a, 2014b), including venting, flaring, exploration, production and upgrading, transport, processing, transmission and storage, as well as distribution networks. The gas distribution leakage is included in our inventory. The fugitive emissions rates (FER) of natural gas is decreasing from 1980 to 2011 (Schwietzke et al., 2014b). For China, we adopted the FER linearly decreases from 4.6% (0.81 kt CH_4/PJ) in 1980 to 2.0% (0.35 kt CH_4/PJ) in 2010. The low and scenario of FER in China decreases from 3.9% in 1980 to 1.8% in 2010, and the high scenario of FER in China decreases from 5.7% in 1980 to 4.9% in 2010. The fugitive CH_4 emissions from gas systems increase from 0.45 [0.38-0.56] Tg CH_4/yr in 1980 to 1.27 [1.14-3.11] Tg CH_4/yr in 2010.

-) page 8, l2: Is the China Env. Stat. Yearbook not showing differences in practices between large versus small or young versus new cities?

[Response] No.

-) page 9, l7: please map carefully in a table for each (sub-)sector the specific proxy datasets (over time) are used; page 9, l14 why is livestock distributed with agricultural gross domestic product and GDP and not with the maps of animal numbers, as available from the geonetwork at the FAO site? Why is the oil & gas distributed with GDP, if there are data available on oil and gas exploitation from NOAA? Why considering only 414 coal exploitation sites, if Liu et al (2015, Nature) has a map of several thousand sites. The two-step distribution as described in lines 19-20 should be used for all (sub-)sectors.

[Response] We added the details for proxy datasets for the spatial mapping (Table S1). In the revised version, we used gridded maps of animal number as the proxy data for CH_4 emissions from livestock, instead of agricultural GDP. For the geographical attribution of fugitive emissions from oil and gas systems, instead of GDP, we applied the spatial distribution of the EDGARv42 gridded maps for fugitive emissions from oil and gas systems with spatial resolution of 0.1 degree by 0.1 degree, scaled by the total emissions from oil and gas systems in each province (Schwietzke et al., 2014a). The population density, oil and gas production sites, and other proxies for transportation routes are used in EDGARv42 to distribute those CH_4 fugitive emissions from oil and gas systems. For coal exploitation, we used data from 414 counties in the previous version, not 414 sites. In each county, there are probably several hundreds of coal production sites. To get a higher spatial resolution, we used the location of 4264 coal production sites from Liu et al. (2015) as proxy data in the revised version. We summed the total annual coal production in each grid of 0.1 degree by 0.1 degree as the weight to distribute the total CH_4 emissions from coal mines in each province.

-) page 10, l8: please carefully derive when the acceleration in CH_4 emissions start, definitely after 2000, but can we even say in 2002 when China joined the WTO?

[Response] We applied piecewise linear regression on the time series of total CH_4 emissions, and found that the acceleration in CH_4 emissions starts from 2002 (the trends of total CH_4 emissions before and after 2002 are 0.5 Tg CH_4/yr^2 and 1.3 Tg CH_4/yr^2, respectively), which is attributed to the acceleration in CH_4 emissions from coal mining after 2002 (the trend of CH_4 emissions from coal mining from 2002 to 2010 is 1.1 Tg CH_4/yr). This could be related to remarkable achievements in economic index, when China joined WTO starting from December, 2001.

-) page 12, l16: Seen the relative large variation in rice emissions over time (in EDGARv4.2 varying from 19.2 to 11.9 Tg CH_4/yr), please compare the emissions of the same years: so the 2005 value of
13.2 Tg CH_4/yr with the NDRC value of 7.9 Tg CH_4/yr and with the Chen (2013) estimate of … in 2005.

[Response] It is revised. Note that Chen et al. (2013) compiled all sites data measured in different years and used rice cultivation area in 2008 to estimate the methane emissions from rice cultivation.

-) page 13, l1: maybe a discrepancy can be found in the definition of "biomass burning". Please have a careful look what is included: vegetal waste burning, agricultural waste burning, crop residue burning, field burning, grassland fires, woodland fires, forest fires, …?

[Response] Biomass and biofuel burning includes firewood and crop residues burnt as biofuel in rural households, as well as disposed crop residues burnt in open field. The CH_4 emissions from wildfire of natural ecosystems (forests, grasslands etc.) are not included in our inventory, because this inventory only includes the anthropogenic methane emissions. We added the definition of "biomass and biofuel burning" in the method section 2.2.3.

-) page 14: l3: EDGARv4.2 uses the CDM of UNFCCC as input for all developing countries on coal mine gas recovery (cfr. IEA's CO2 from fuel combustion book, part III, GHG).

[Response] We also considered the increased utilization of CH_4 from coal bed methane (CBM) and coal mine methane (CMM) as accounted for by the increasing utilization fraction in our study (Page 7, lines 1-5), which increased by 4% in the last decade (from 5.2% in 2000 to 9.2% in 2010). Please also see the above response to the CH_4 recovery from coal mines.

-) page 16: please give a quantitative evaluation of the mitigation measures and an outlook on the further reduction potential based on the references. Page 16, l6: please evaluate carefully that new PVC gas distribution networks are better than the old steel networks and that new transmission pipelines (such as for the connection Russia and China) are not expected to lead to high leakages. Input on these issues can be gained also from the Chapter 5 of the AMAP report on CH_4 from Hoeglund-Isaksson et al. (2016)

[Response] Please see the above response to quantitatively estimate the reduction potentials. In this study, we assumed that the fugitive emissions rates (FER) from natural gas systems linearly decreased from 1980 to 2010 because of reduced unintended leakage and technically leakage control. In 2010, the FER in China is 2.0%, including production emissions and the leakage from natural gas production and distribution networks. We agree that PVC pipeline is better than the old steel pipeline. In the 2000s, the networks of natural gas distribution in cities of China are PVC pipelines. If China follow the rates of maximum technically feasible reduction potentials in Höglund-Isaksson et al. (2015), the leakage of long-distance gas transmission could be reduced by 60% and the total fugitive emissions from oil and gas systems can be reduced by 58% in 2030.

References

Dong, H., Tao, X., Xin, H. and He, Q.: Comparison of enteric methane emissions in China for different IPCC estimation methods and production schemes, Trans. Asae, 47(6), 2051–2057, 2004.

IPCC (Intergovernmental Panel on Climate Change): 2006 IPCC Guidelines for National Greenhouse Gas Inventories, IGES, Japan., 2006.

Schwietzke, S., Griffin, W. M., Matthews, H. S., and Bruhwiler, L. M. P.: Global Bottom-Up Fossil Fuel Fugitive Methane and Ethane Emissions Inventory for Atmospheric Modeling, ACS Sustainable Chemistry & Engineering, 2, 1992-2001, 10.1021/sc500163h, 2014a.

Schwietzke, S., Griffin, W. M., Matthews, H. S., and Bruhwiler, L. M. P.: Natural gas fugitive emissions rates constrained by global atmospheric methane and ethane, Environmental Science and Technology, 48, 7714-7722, 10.1021/es501204c, 2014b.

The National Development and Reform Commission (NDRC): The People's Republic of China national Greenhouse gas inventory, 2014. Beijing, China Environmental Press.

Zheng, S., Wang, Y. A. and Wang, Z. Y.: Methane emissions to atmosphere from coal mine in China, Saf. Coal Mines, 36(2), 29–33, 2006. (in Chinese)